Dynamics Analysis of Irregular Steel Building with and Without Diagrid Structure Using ETABS

Ritika Gupta[1] and Vinod Kumar Modi[2]
[1]*M.Tech. Scholar, Kautilya Institute of Technology & Engineering, Jaipur*
[2]*Associate Professor, Kautilya Institute of Technology & Engineering, Jaipur*

Abstract: **Recent trends indicate that the unique geometric design of diagrid structural systems has made them increasingly popular in high-rise buildings, combining aesthetic appeal with structural efficiency. With the global rise in multi-story construction, diagrid systems are being widely adopted. These systems are among the most effective methods for countering lateral forces, as they enhance both the structural integrity and visual design of buildings.**

Research has highlighted that the primary causes of R.C. structural failures are the abnormal distribution of weight, stiffness, and strength, or irregular geometric configurations. Many existing buildings exhibit defects resulting from operational and aesthetic demands. Engineers must prioritize earthquake-resistant designs to limit damage to acceptable levels, safeguarding occupants' lives at a reasonable cost. Earthquake-resistant structures are designed to withstand ground shaking; while they may sustain severe damage, they are built to avoid collapse during strong earthquakes.

This study compares irregular steel structures with and without diagrids under earthquake conditions specified in IS 1893:2016. The analysis considers an irregular steel building with a configuration of B+G+19 stories, a plan dimension of 24m x 24m, situated in seismic zone IV with medium soil conditions. The modeling and analysis are conducted using ETABS 2019 software, and all structural components are designed in accordance with IS 456:2000. The study evaluates the performance of both steel buildings under dynamic analysis, considering wind effects, lateral forces, and load combinations as per IS code. Key parameters such as maximum storey drift, base reactions, storey stiffness, and storey forces are analyzed to assess the structures' behavior.

Keywords: **Irregular Steel building, Diagrids, Seismic Analysis, ETABS High-rise structure, structural irregularity, lateral displacement, Structural Stability.**

I. INTRODUCTION

Irregular structures form a significant part of urban infrastructure, with vertical irregularities often being a key cause of failure during earthquakes. Structural failures typically originate at points of weakness caused by discontinuities in stiffness, mass, or geometry. Buildings with these discontinuities, termed irregular structures, experience notable effects on their seismic performance, especially in high seismic zones where design and analysis become complex.

While irregular structures are often chosen for their functional and aesthetic appeal, they cater to evolving client demands for unique, creative designs that serve as architectural landmarks and reflect stakeholders' identities. Despite their challenges, these structures offer futuristic and visually striking impressions. The Indian code provides guidelines to assess irregularity levels and outlines penalties and restrictions to address them. Irregularities are broadly classified into two main types, emphasizing the need for careful evaluation in design.

The origin of diagonal structures can be attributed to the Russian visionary Vladimir Shukhov. A pioneer in analytical methods across various disciplines, Shukhov's contributions to early Soviet Russia's constructivism remain unparalleled. As a leading engineer and mathematician of the late 19th and early 20th centuries, he designed hyperboloid, thin shell, and tensile structures that exemplify exceptional refinement and elegance.

The diagrid structural system is highly efficient, reducing the need for interior columns and offering significant flexibility in plan design. It has emerged as an advanced solution for lateral load resistance, effectively managing lateral displacements while simplifying the structural system. With its superior stiffness and lighter weight compared to other models, the diagrid structure is both efficient and economical.

Diagrid systems provide excellent solutions for lateral load resistance in terms of reducing steel weight, managing lateral displacements, and enhancing stiffness. They are robust enough to withstand wind forces at considerable heights. The minimal use of columns maximizes interior space and enhances the building's aesthetic appeal, allowing efficient facade planning. By eliminating interior and corner columns, the diagrid system enables greater flexibility in floor plan design, making it an ideal choice for modern architecture.

Objectives:
1. To calculate the lateral design forces on irregular steel buildings comprises of high-rise building with or without diagrids using dynamic analysis and compare the different structures' results.
2. To compare the analysis results of shear force, bending moment, storey drift, storey stiffness and base reaction values of both the buildings.
3. To perform dynamic analysis of irregular steel buildings with and without diagrid structures using ETABS.
4. To evaluate and compare the seismic performance of diagrid and conventional (non-diagrid) irregular steel buildings.
5. To model irregular steel building configurations in ETABS with and without diagrid systems.
6. To perform modal analysis and determine fundamental periods, mode shapes, and mass participation factors.
7. To carry out Response Spectrum and/or Time History analysis to evaluate dynamic behavior.
8. To assess and compare structural responses such as Story displacement, Story drift, Base shear, Lateral stiffness, Member forces.
9. To study the influence of geometric irregularity on the dynamic response of both structural systems.
10. To provide design recommendations based on comparative performance.

II. LITERATURE REVIEW

Rajeshwari B, Tejaswini B R, Gourav Kumar Saxena (2024) studied on G+15 storey diagrid steel building with a regular 18 m × 18 m floor plan was analyzed and designed using ETABS software. Structural members were designed as per IS 800:2007, considering all load combinations. The study evaluated parameters like storey displacement and storey drift for different story heights and diagrid angles to identify the best model. Devender Kumar Suthar, Sabhilesh Singh (2023) researched on seismic performance of a 2B+G+18 storey irregular steel building with and without diagrids was compared. Located in Zone IV, the structure was modeled and analyzed using ETABS 2019, adhering to IS 456:2000 and IS 1893:2016. The study considered lateral wind effects and dynamic loads, assessing the structure under different conditions. M. Satya Sai Kiran Chowdary, Himath Kumar Y, Lingeshwaran N (2021) evaluated on Seismic performance of 20-storey concrete and steel diagrid structures was analyzed using the response spectrum method, with the time history method applied to concrete diagrids. Structural members were designed per IS 456:2000, and seismic analysis was conducted following IS 1893:2002 and ASCE7-10. Parameters like storey shear, drift, displacement, time period, and structural weight were evaluated.

H. M. Meghana, Sabyath P Shetty (2021), a 36-storey steel diagrid structure was studied to analyze the effects of bracing angle, aspect ratio, and different diagrid shapes. ETABS software was used for wind and seismic load analysis. Parameters like time period, storey displacement, and storey drift were analyzed to assess performance according to IS 800:2007. Vahid Mohsenian, Saman Padashpour, Iman Hajirasouliha (2020), seismic reliability of diagrid systems was evaluated for 16, 24, and 32 storey buildings with a 65° diagrid angle. Supply and demand response modification factors were calculated, providing insights into multi-level performance-based design for diagrid structures. Chetan S. Pattar, Varsha Gokak (2018) response spectrum method was used to analyze a 16-storey steel structure with C-type and L-type plan irregularities. Comparative results were presented for parameters such as base shear, top storey displacement, and storey drift.

Akshat, Gurpreet Singh (2018), 60-storey building with a 216 m height and a regular 48 m × 48 m floor plan was analyzed using response spectrum methods in seismic Zone IV. The study assessed varying diagrid patterns and angles for structural economy and efficiency.

Vinay A. C., Manjunath N. Hegde (2017), 50-storey steel diagrid structure with various angles (30°, 45°, 55°, 65°) was analyzed using ETABS. Results on parameters like time period, base reactions, storey drift, and displacement helped identify optimal diagrid angles.

Deep Bajoria, Gaurav Banwat, Avishekh Jaiswal, Saurabh Agarwal (2017) researched on G+36 storey RCC diagrid structure with a 36 m × 36 m plan was analyzed using the response spectrum method. Comparative analysis for parameters like base reactions, time period, and storey drift was conducted to evaluate structural efficiency.Harish

Varsani, Narendra Pokar, Dipesh Gandhi (2015) Conventional and diagrid structural systems were compared for a 24-storey building. Dynamic analysis revealed the efficiency of diagrid systems in reducing storey drift and lateral displacement. Khalid K. Shadhan (2015) studied on Optimal diagrid angles were studied for 24, 48, and 72 storey buildings. ETABS was used to analyze configurations, identifying diagrid angles that minimized lateral drift for each height range. Prashant T. G., Shrithi S. Badami, Avinash Gornale (2015) researched on 12-storey diagrid structure was modeled in SAP 2000 to assess seismic performance using pushover analysis. The study evaluated design adequacy based on spectral displacement and acceleration. Sree Harsha J., K. Raghu, G. Narayana (2015) G+24 storey diagrid structures were analyzed with uniform diagrid angles. Parameters like storey shear, displacement, and time period were compared to assess structural behavior. Sepideh Korsavi, Mohammad Reza Maqhareh (2014) researched on thirty diagrid cases were analyzed to study evolutionary trends in architectural and structural concepts. The analysis highlighted the adaptability of diagrid systems in various building types and functions.

III. METHODOLOGY

In this study, Irregular High-Rise Steel Building (B+G+19) with or without Diagrids in Zone IV is considered. In (Fig. 3.1 (a)), Irregular B+G+19Storey high-rise steel building without diagrid at a height equal to 3m for each level. The grade of steel use is fe 350.

For the present work, modelling has been done for irregular high-steel building by taking IS code into account. B+G+19 storey steel building with storey height 3 meters for all and with a plan size of 24mx24m is considered. Live load on all the structures is taken as 4 Kn/m2 on floor levels and 1.5 Kn/m2 on the roof level and slab thickness as 150mm. Both models are modelled in ETABS 2019 software taking all the codal provisions into account.

- L- shape structure without diagrid
- L-shape structure with diagrid

Table 1 Building Parameters

Parameter	Details
Details of Building	High Rise B+G+19 Storey Steel building
Plan configuration	24m x 24m
Floor to Floor Height	3m
Building Height	60m
Grade of steel	Fe-350
Size of Column	450mmX450mm
Size of Beam	300mmX450mm
Size of Slab	100 mm
IS-Code referred	IS 800:2007
Live Load	3Kn/m2
Live Load on Roof	2Kn/m2
Soil Type	Medium soil
Zone considered	Zone IV
Zone Factor	0.24
Importance Factor	1.2
Response Reduction Factor	3
Damping	0.05

IV. RESULTS AND DISCUSSION

The effects of base shear, shear force, bending moment, storey drift, and displacement differ significantly in diagrid regular and irregular structure.

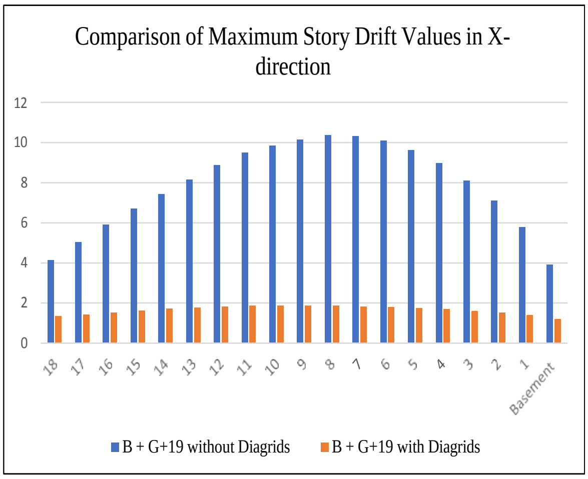

Fig. 1 Storey Drift values in B+G+19 (X direction)

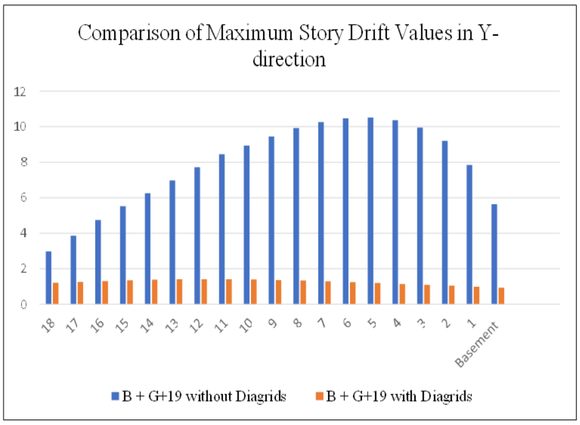

Fig. 2 Storey Drift values in B+G+19 (Y direction)

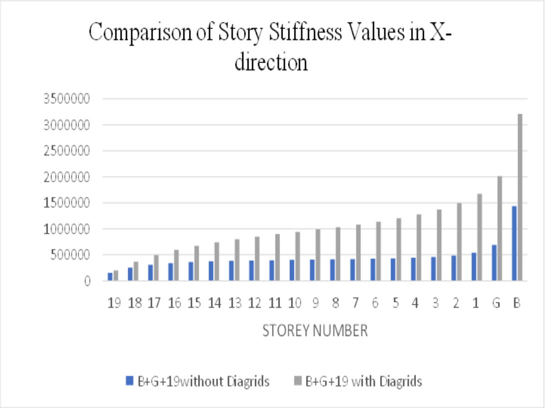

Fig. 3 Storey Stiffness in B + G+19 (X direction)

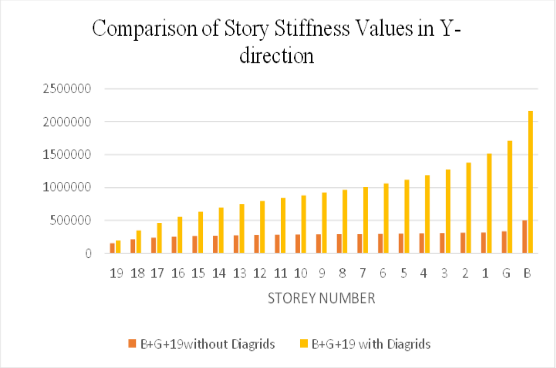

Fig. 4 Storey Stiffness in B + G+19 (Y direction)

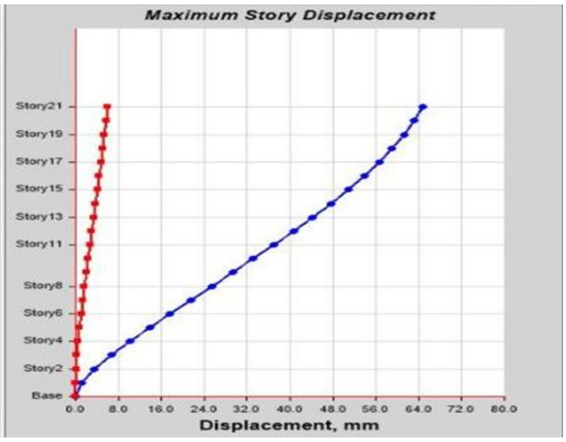

Fig. 5 Storey Displacement in B+G+19 (X direction) without diagrids

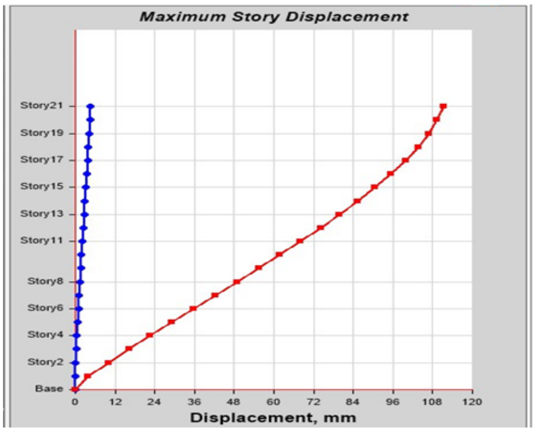

Fig. 6 Storey Displacement in B+G+19 (Y direction) without diagrids

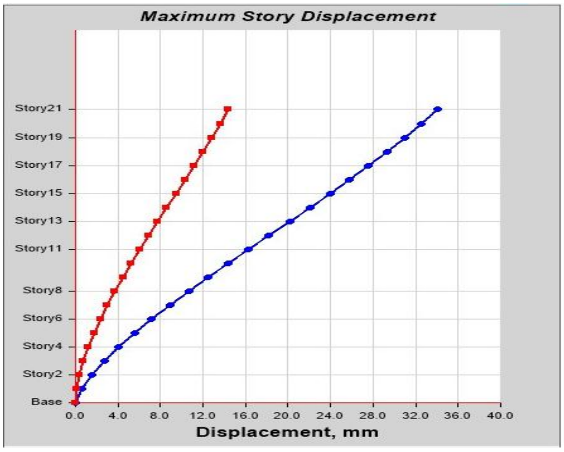

Fig. 7 Storey Displacement in B+G+19 (X direction) with diagrids

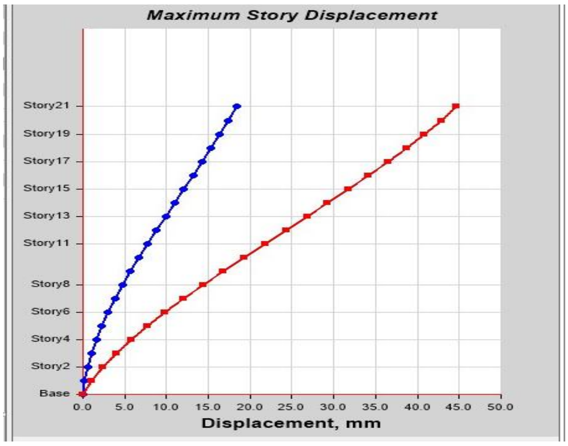

Fig. 8 Storey Displacement in B+G+19 (Y direction) with diagrids

Fig. 9 Storey Shear in B+G+19 (X & Y direction) without diagrids

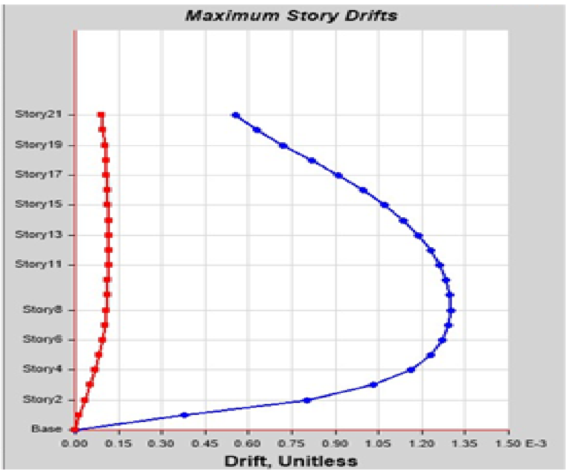

Fig. 10 Storey Drift in B+G+19 (X & Y direction) without diagrids

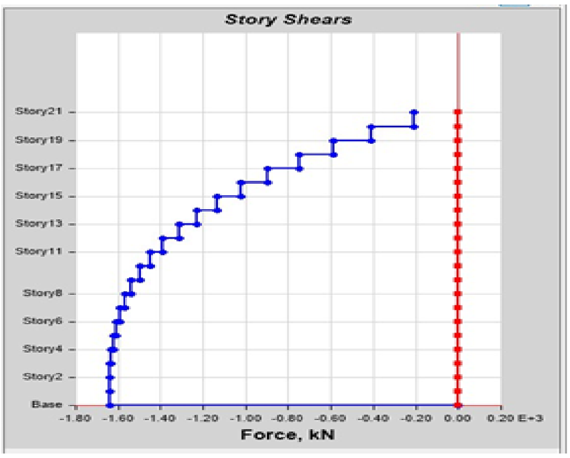

Fig. 11 Storey Shear in B+G+19 (X & Y direction) with diagrids

Fig. 12 Storey Drift in B+G+19 (X & Y direction) with diagrids

V. CONCLUSIONS

This study systematically assessed the structural performance of B+G+19 storey irregular L-shaped steel buildings in Zone IV with and without diagrid configurations using the Response Spectrum method in ETABS. Seismic parameters were defined according to IS 1893:2016. The findings highlighted significant differences in performance and structural behavior under seismic loading, with diagrid systems enhancing lateral stability and overall resilience against seismic forces.

- Story Drift: Diagrid structures reduced story drift by approximately 80%, with a notable decrease at story 12 in the EQX direction (Without Diagrid: 8.871 mm; With Diagrid: 1.832 mm).
- Base Reaction: Base shear values in diagrid models were substantially higher, reflecting enhanced lateral force resistance (EQX: Without Diagrid: -1282.77 kN; With Diagrid: -4881.10 kN).
- Storey Stiffness: Diagrid models exhibited ~19 times greater stiffness at story 10 in the EQX direction (Without Diagrid: 101,293 kN/m; With Diagrid: 2,009,465 kN/m), reducing vulnerability to lateral displacement.
- Shear Forces: Diagrid structures demonstrated increased storey shear capacity, improving seismic resistance (At story 10 VX: Without Diagrid: 837.62 kN; With Diagrid: 3251.52 kN).
- Bending Moments: Maximum bending moments were significantly higher in diagrid structures, enhancing structural capacity (At story 10 Mx: Without Diagrid: 15,917.12 kNm; With Diagrid: 56,581.28 kNm).

Overall, the diagrid system enhanced lateral stiffness, reduced story drift, and offered superior resistance to seismic and wind loads. It also optimized material usage, making it effective for complex geometries and irregular structures.

REFERENCES

[1] M Satya Sai Kiran Chowdary, Himath Kumar Y and Lingeshwaran N Sci. “Seismic analysis of tall concrete and steel diagrid structure using response spectrum and time hiStorey method in e-tabs,” N Sci. Eng., 1136 012035, 6th-7th March 2021, Madhya Pradesh, India.

[2] H M Meghana, Sabyath P Shetty. “A review of the diagrid structural system for skyscraper steel structures,” e-ISSN: 2582-5208, Volume: 03, Issue: 08, August 2021.

[3] M. Heshmati, A.A. Aghakouchak. “Quantification of seismic performance factors

of steel diagrid system," The Structural Design of Tall and Special Buildings, 28 (2019) 1-14.

[4] E. Asadi, H. Adeli. "Seismic performance factors for low-to mid-rise steel diagrid structural systems," The Structural Design of Tall and Special Buildings, 27 (2018) 1-18.

[5] C. Liu, Q. Li, Z. Lu, H. Wu. "A review of the diagrid structural system for tall buildings," The Structural Design of Tall and Special Buildings, 27 (2018) 1-10.

[6] Chetan S. Pattar, Prof. Smt. Varsha Gokak. "Analysis of Diagrid Structures with Plan Irregularity," e-ISSN: 2395-0056, p-ISSN: 2395-0072, Volume: 05, Issue: 08, August 2018.

[7] Akshat, Gurpreet Singh. "Dynamic analysis of diagrid structural system in high-rise steel buildings," Volume 9, Issue 8, August 2018.

[8] Yogeesh H.S, V. Devaraj. "A Seismic Study on Diagrid Structure," International Journal for Research in Applied Science & Engineering Technology, Volume 6, Issue VI, June 2018.

[9] Vinay A.C., Manjunath N. Hegde. "Comparative Analysis of Conventional Steel Structure with Diagrid Structures of Varied Angles," e-ISSN: 2395-0056, p-ISSN: 2395-0072, Volume: 04, Issue: 09, September 2017.

[10] Computers and Structures Inc. (CSI). Structural and Earthquake Engineering Software, ETABS, Extended Three-Dimensional Analysis of Building Systems Nonlinear Version 15.2.2, Berkeley, CA, USA, 2015.

[11] Khushbu Jani, Paresh V. Patel. "Analysis and Design of Diagrid Structural System for High-Rise Steel Buildings," Procedia Engineering, 51 (2013) 92-100.

[12] Kim, J., & Lee, Y.-H. "Seismic performance evaluation of diagrid system buildings," The Structural Design of Tall and Special Buildings, 21(10), 736-749, 2012.

[13] J. Kim, Y.H. Lee. "Seismic Performance Evaluation of Diagrid System Buildings," The Structural Design of Tall and Special Buildings, 21 (2012) 736-749.

[14] K. Moon. "Design and construction of steel diagrid structures," NSCC, pp. 392-405, 2009.

[15] Ali, M. M., & Moon, K. "Structural Developments in Tall Buildings: Current Trends and Future Prospects," Architectural Science Review, Vol. 50.3, pp. 205, 2007.

[16] IS:1893 (Part 1)- 2016, "Criteria for Earthquake Resistant Design of Structures Part 1 General Provisions and Buildings", Bureau of ndian Standard, New Delhi.

[17] IS:800-2007, "General Construction in Steel – Code of Practice", Bureau of Indian Standard, New Delhi.